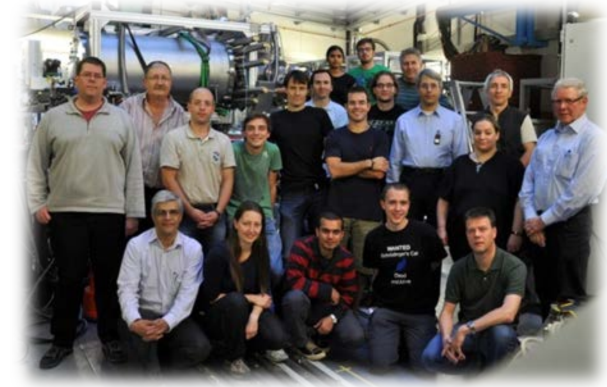
AHEAD OF ITS TIME FOR 150 YEARS

LaSpec

Laser Spectroscopy of short-lived nuclei at FAIR



An informal summary of the gas catcher activities at the FRS (& LaSpec)

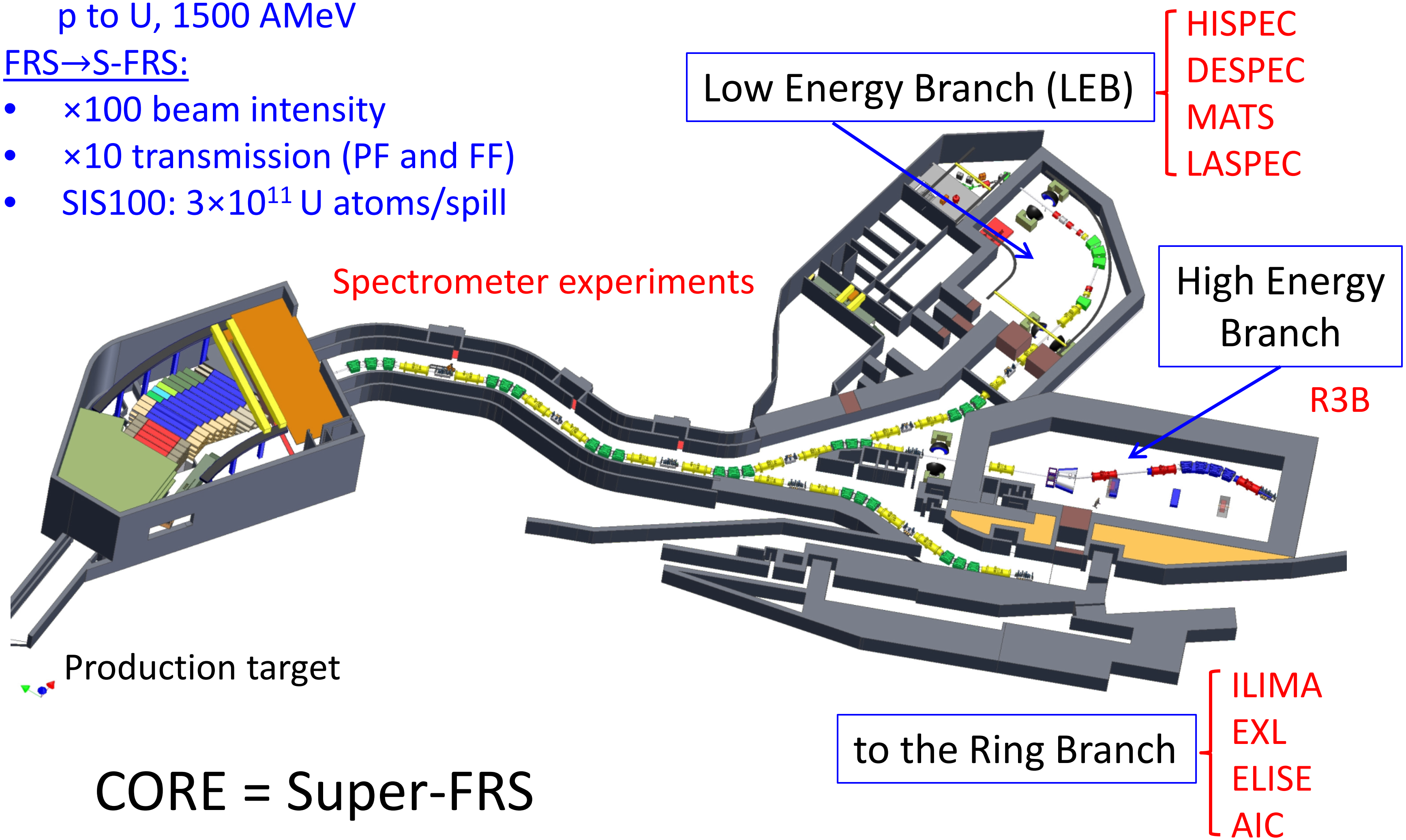
Iain Moore

The NUSTAR facility

- Primary beams from SIS100:
  p to U, 1500 AMeV

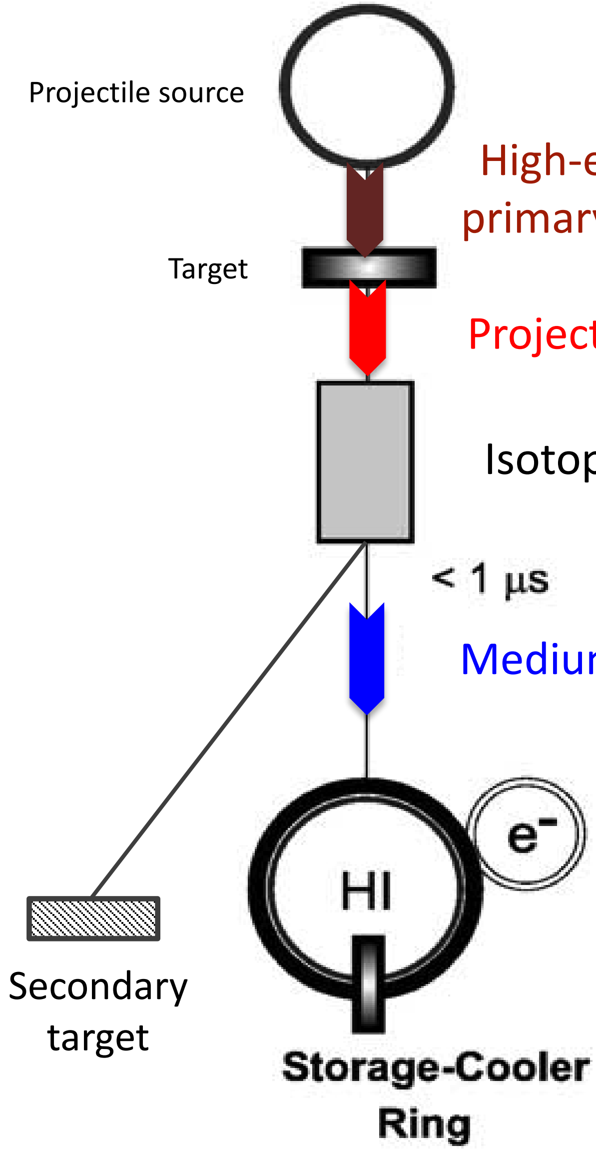
FRS→S-FRS:

- ×100 beam intensity
- ×10 transmission (PF and FF)
- SIS100: 3×10^{11} U atoms/spill

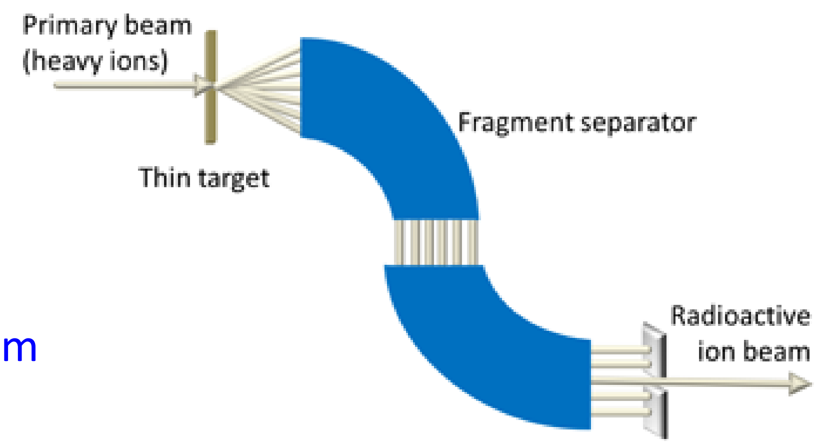


CORE = Super-FRS

In-flight production of RIBs



First in-flight separator, Oak Ridge (1958)

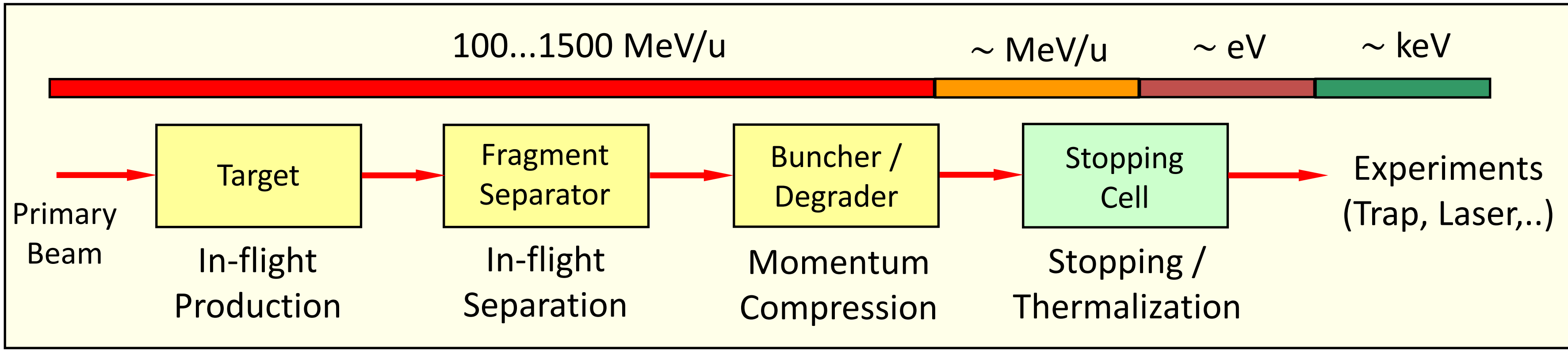


- Very fast separation, access to µs half-lives
- Beams of ALL elements
- Often poor beam quality
- Precision experiments at low-energy not directly accessible.

Low Energy Branch of the Super-FRS

AHEAD OF ITS TIME FOR 150 YEARS

LEB: High-precision experiments with in-flight separated exotic nuclei almost at rest, (production by projectile fragmentation / fission)



MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

- High accuracy mass measurements
- In-trap conversion electron and alpha spectroscopy
- Trap-assisted spectroscopy

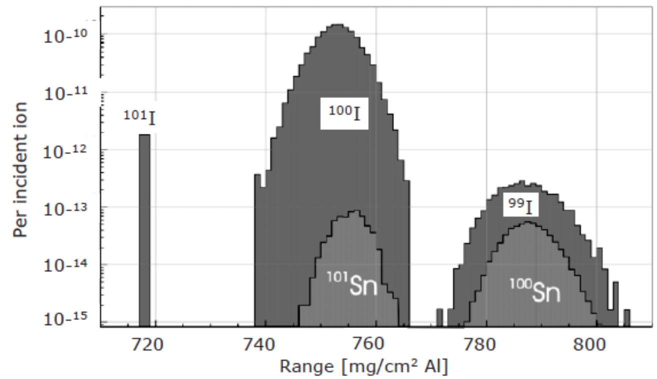
LaSpec (Laser Spectroscopy)

- Collinear laser spectroscopy of ions and atoms
- β-NMR
- Resonance ionization spectroscopy

Eur. Phys. J. Special Topics 183 (2010) 1

Challenging design goals for a gas catcher

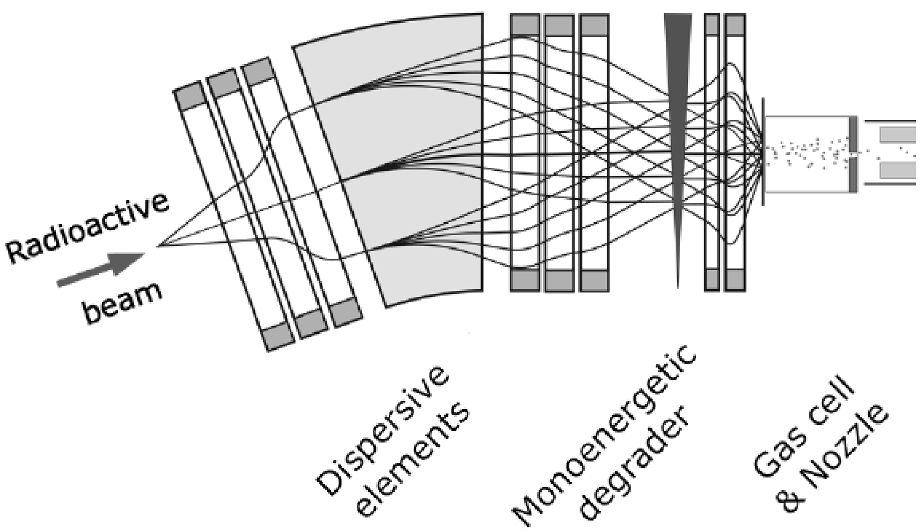
- Energy straggling: determines areal density of gas needed for efficient stopping
- Impurities: loss of ions due to molecular formation
- Ionization density: space charge
- Beam size

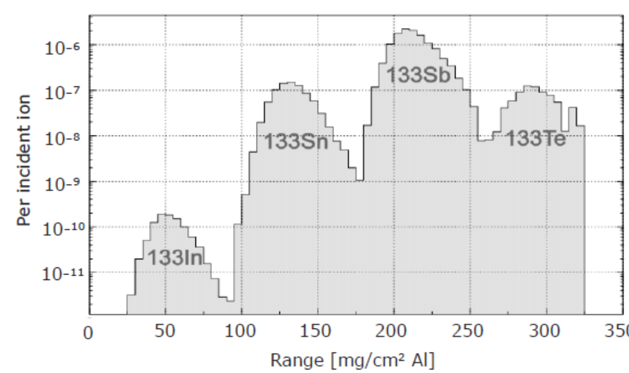


^{100}Sn projectile fragments

- unwanted isotopes well separated
- more intense fragments stop earlier

Energy/range bunching device



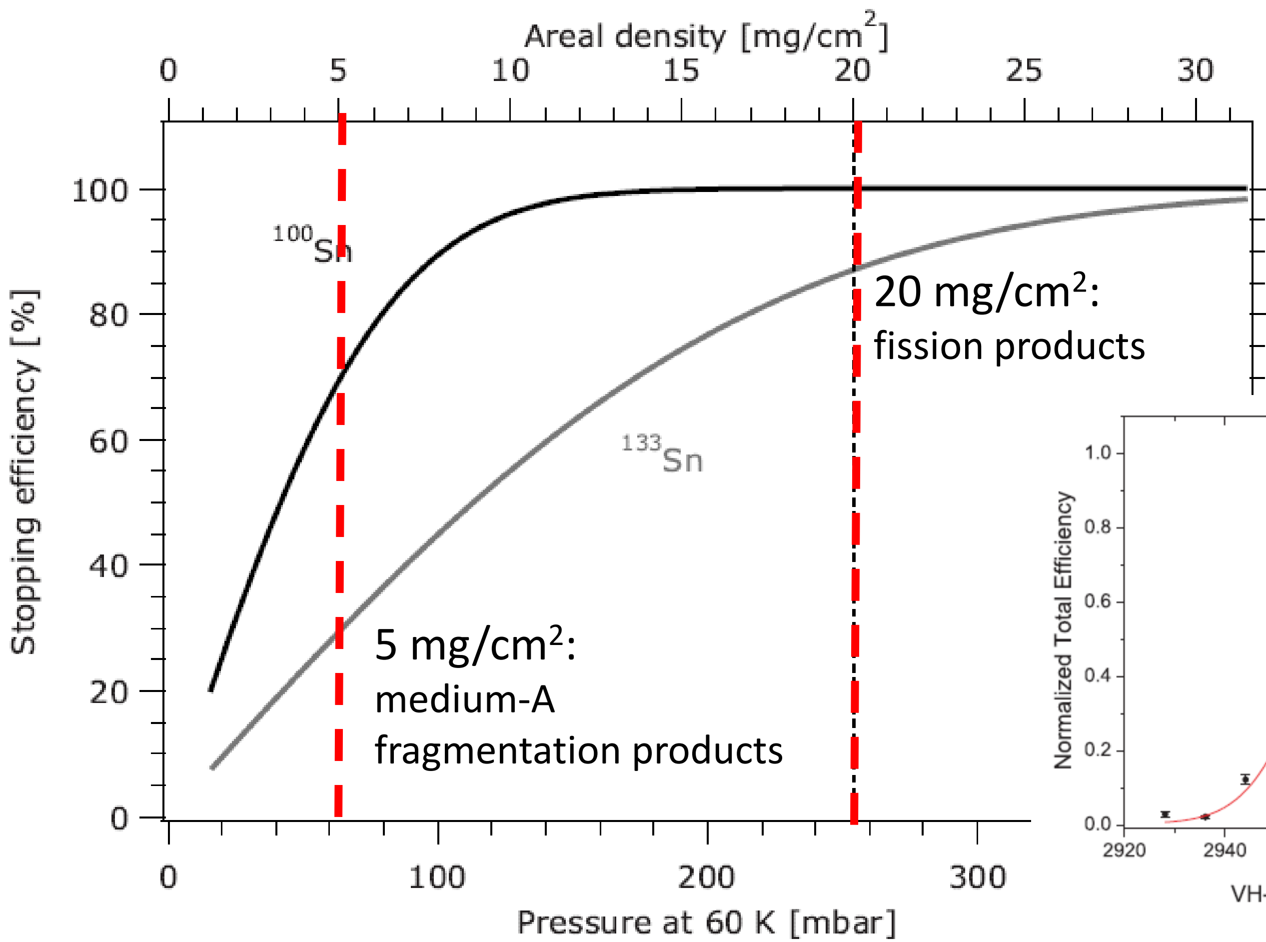


^{133}Sn fission fragments

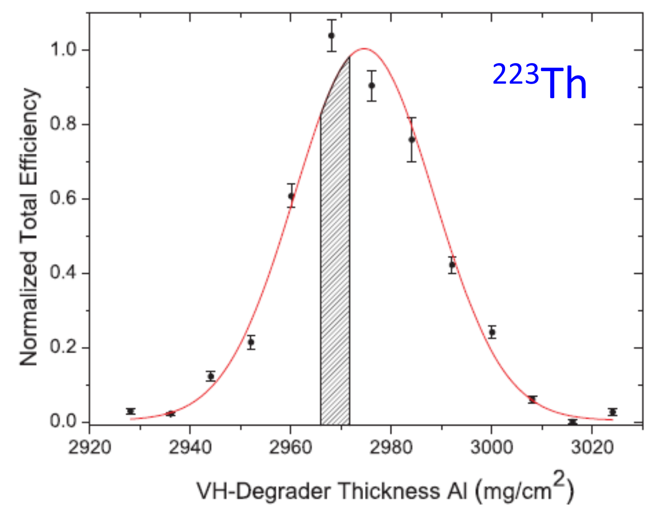
- poorer quality beams
- isobars have longer range

Stopping efficiency vs areal density

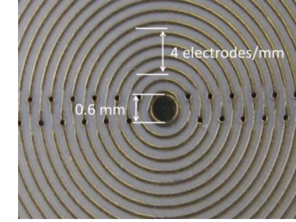
Range straggling calculated from standard deviation of previous range distributions (given in Al, but converted to He).

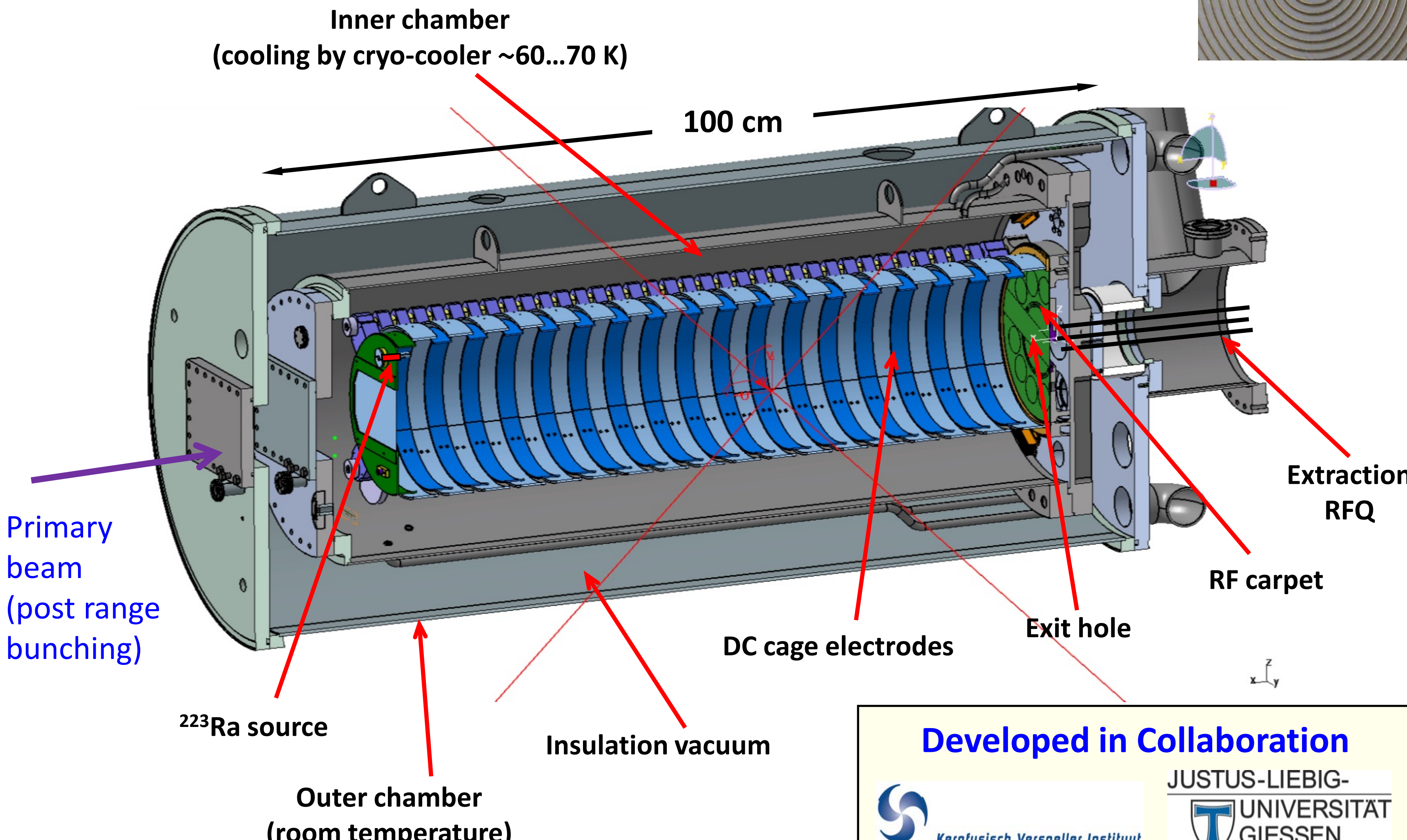


Beam window:
25 cm × 10 cm
Design goal:
20 mg/cm²



First generation cryogenic stopping cell





Developed in Collaboration

Kernfysisch Versneller Instituut

university of groningen

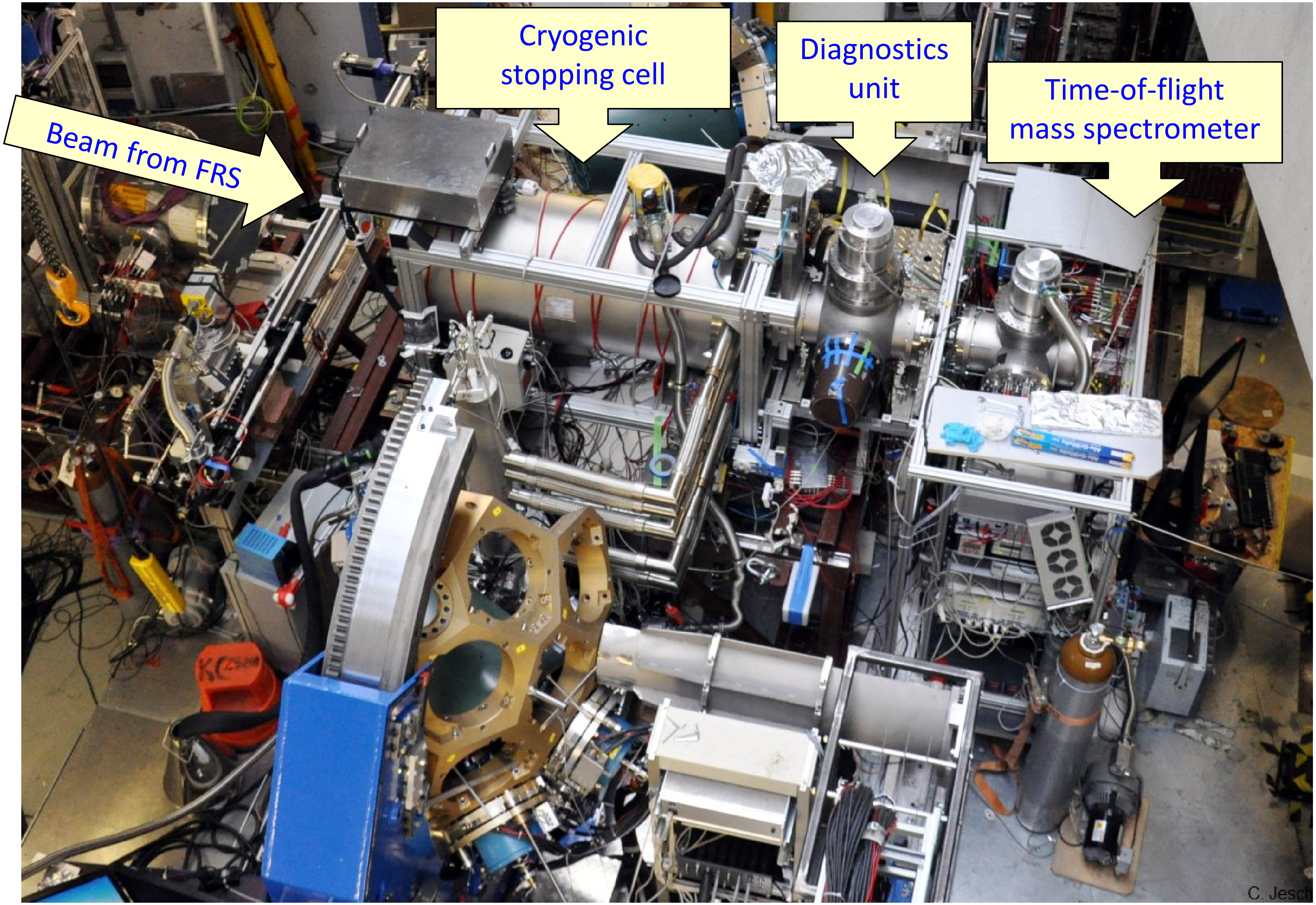
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GSI

M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

M.P. Reiter, Master thesis, Justus-Liebig-University Gießen, 2011

Setup at GSI, S4 cave, Oct. 2011 / July 2012



Cooling system design and performance

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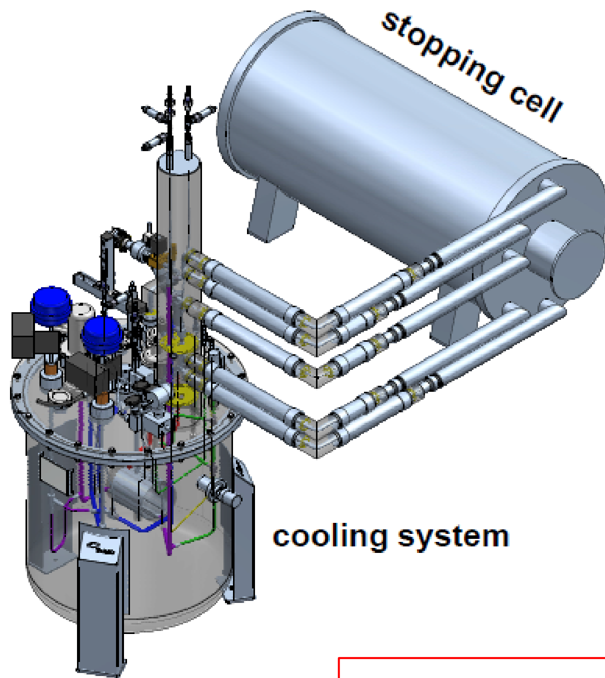
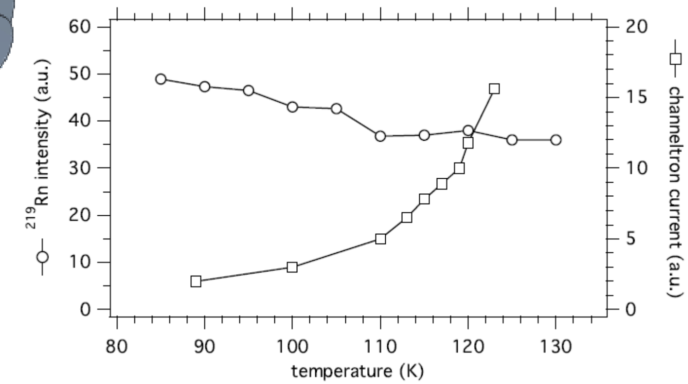
FOR 150 YEARS

Twin cooling channels





Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

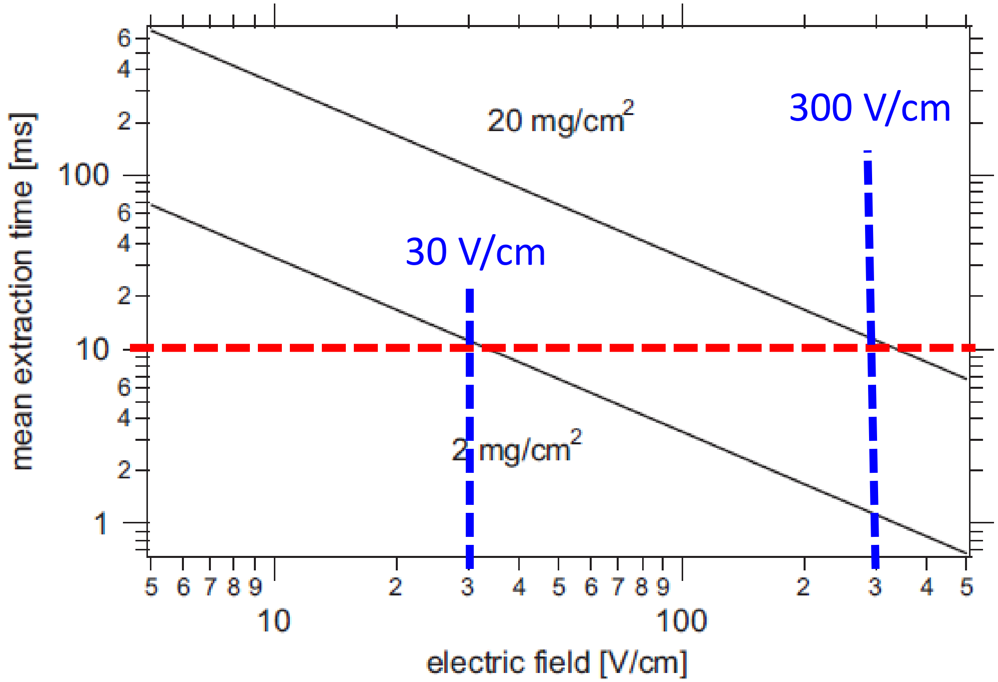
ELSEVIER

Design, construction and cooling system performance of a prototype cryogenic stopping cell for the Super-FRS at FAIR

M. Ranjan[a], P. Dendooven[a,*], S. Purushothaman[b], T. Dickel[b,c], M.P. Reiter[c], S. Ayet[b], E. Haettner[b,c], I.D. Moore[d], N. Kalantar-Nayestanaki[a], H. Geissel[b,c], W.R. Plaß[b,c], D. Schäfer[c], C. Scheidenberger[b,c], F. Schreuder[a], H. Timersma[a], J. Van de Walle[a], H. Weick[b]

- 2011 expt: lN_2cooling (gas T~100 K)
- 2012: Cryocooler-based system
- Min. temp of 72K reached (~design goal)
- Operational temp <110K after 10h cooling
- ^{219}Rn survival and extraction: ~30%
- Largest areal density off-line ~7mg/cm^2
- On-line 3.1 mg/cm^2 used
- DC of 30V/cm applied across the cell

Extraction time



Contents lists available at ScienceDirect
Nuclear Instruments and Methods in Physics Research B
journal homepage: www.elsevier.com/locate/nimb

The FRS Ion Catcher – A facility for high-precision experiments with stopped projectile and fission fragments

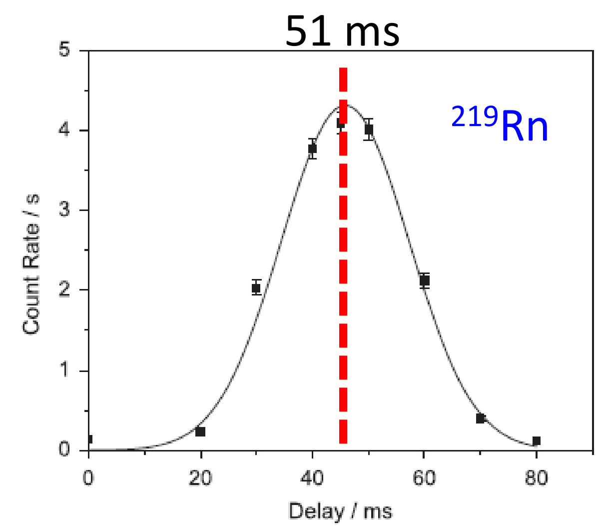
W.R. Plaß[a,b,*], T. Dickel[a,b], S. Purushothaman[b], P. Dendooven[c], H. Geissel[a,b], J. Ebert[a], E. Haettner[a,b], C. Jesch[a], M. Ranjan[c], M.P. Reiter[a], H. Weick[b], F. Amjad[b], S. Ayet[b], M. Diwisch[a], A. Estrade[b], F. Farinon[b], F. Greiner[a], N. Kalantar-Nayestanaki[c], R. Knöbel[a,b], J. Kurcewicz[b], J. Lang[a], I. Moore[d], I. Mukha[b], C. Nociforo[b], M. Petrick[a], M. Pfützner[b,e], S. Pietri[b], A. Prochazka[b], A.-K. Rink[a], S. Rinta-Antila[d], D. Schäfer[a], C. Scheidenberger[a,b], M. Takechi[b], Y.K. Tanaka[b], J.S. Winfield[b], M.I. Yavor[f]

Extraction time from middle of cell ~25 ms

Mass of ^{213}Rn measured, $T_{1/2}$ = 19.5 ms

<u>Design goal</u>:

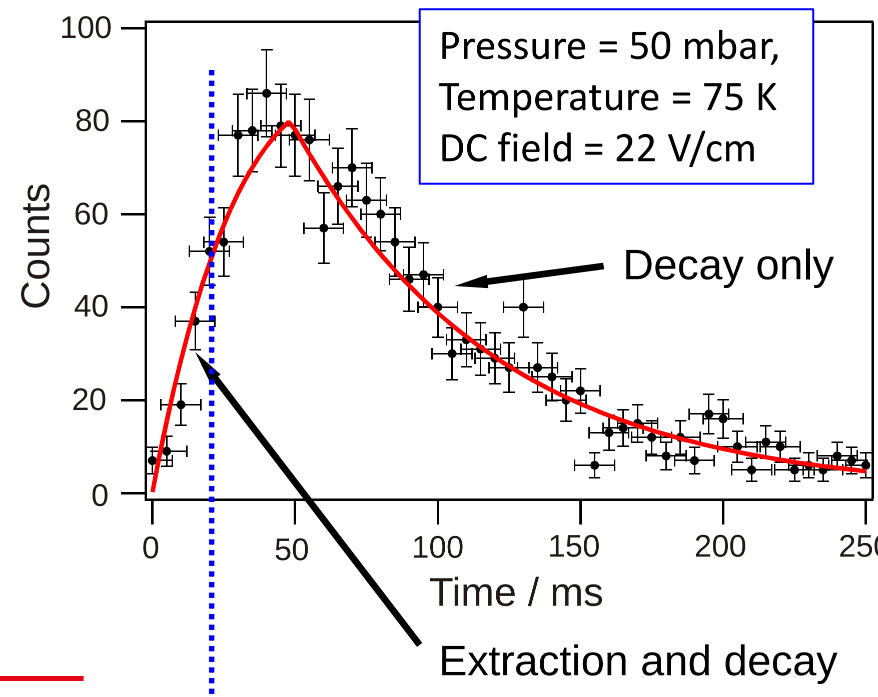
- Short-lived isotopes ~10 ms
- Extraction time α areal density, 1/α to electric field
- "Ideal" limitation due to Paschen curve



Stopping and extraction efficiencies

	Exp. I	Exp. II
p (mbar)	98 ± 5	47 ± 2
T (K)	100 ± 2	78 ± 2
AD in He (mg/cm^2)	4.9 ± 0.3	3.1 ± 0.2
^{223}Th		
σ_R in Al (mg/cm^2)	13.4 ± 0.7	13.7 ± 0.8
ϵ_{stop}	$(27.0 \pm 2.4)\%$	$(15.9 \pm 1.8)\%$
ϵ_{total}	$(11.6 \pm 1.6)\%$	$(9.9 \pm 1.5)\%$
$\epsilon_{sur+ext}$	$(43 \pm 7)\%$	$(62 \pm 12)\%$
^{221}Ac		
$\epsilon_{stop,calc}$		$(15.7 \pm 1.8)\%$
ϵ_{total}		$(7.7 \pm 1.6)\%$
$\epsilon_{sur+ext}$		$(49 \pm 11)\%$
^{219}Rn		
$\epsilon_{stop,calc}$	$(25.0 \pm 2.4)\%$	
ϵ_{total}	$(14.5 \pm 2.0)\%$	
$\epsilon_{sur+ext}$	$(58 \pm 9)\%$	

Extraction of ^{221}Ac ($T_{1/2}$ = 52 ms)



Mean T_{extr} = 23 ms


S Purushothaman

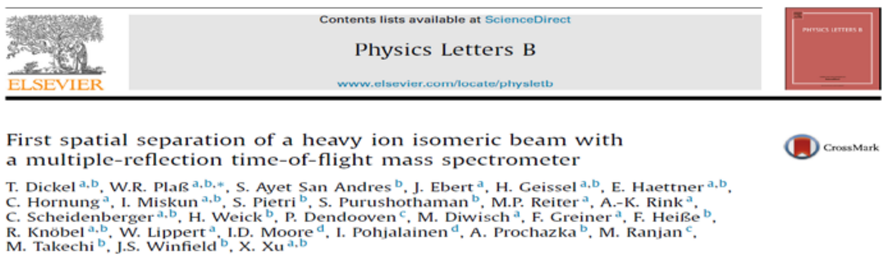
First experimental results of a cryogenic stopping cell with short-lived, heavy uranium fragments produced at 1000 MeV/u

S Purushothaman, M P Reiter, E Haettner, P Dendooven, T Dickel, H Geissel, J Ebert, C Jesch, W R Plaß, M Ranjan, H Weick, F Amjad, S Ayet, M Diwisch, A Estrade, F Farinon, F Greiner, N Kalantar-Nayestanaki, R Knöbel, J Kurcewicz, J Lang, I D Moore, I Mukha, C Nociforo, M Petrick, M Pfützner, S Pietri, A Prochazka, A-K Rink, S Rinta-Antila, C Scheidenberger, M Takechi, Y K Tanaka, J S Winfield and M I Yavor

2013 *EPL* **104** 42001

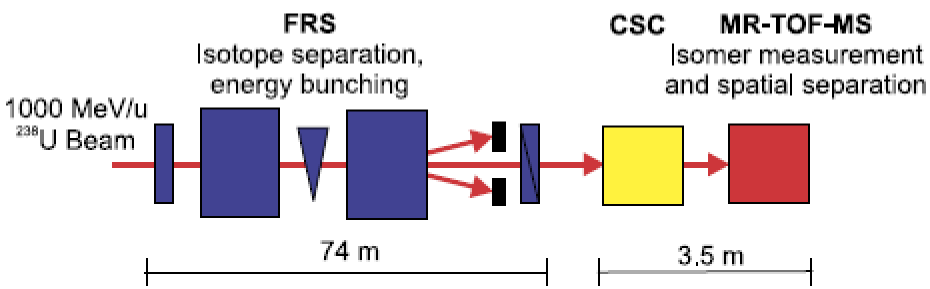
Beam intensities: few 100 to 2000 s^{-1} ≡ ~10^7 He^+ ion – electron pairs/cm^3.s

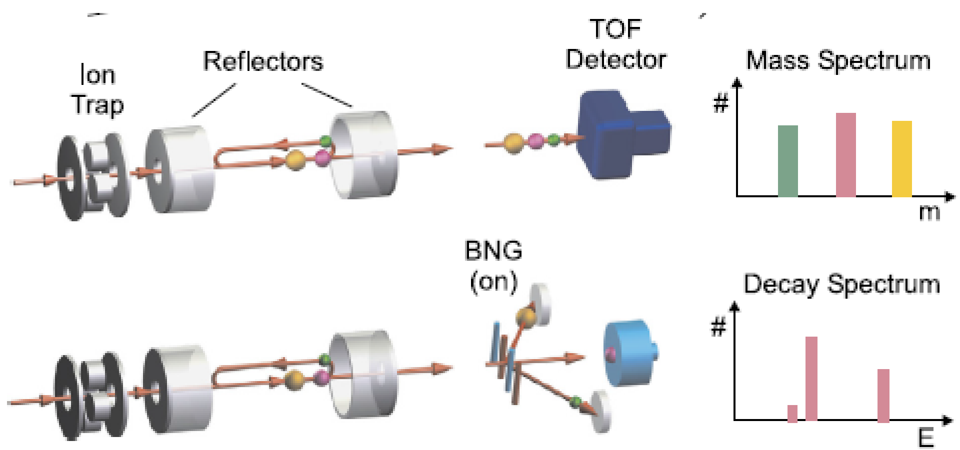
First "physics" measurement at the FRS Ion Catcher (Oct. 2014)

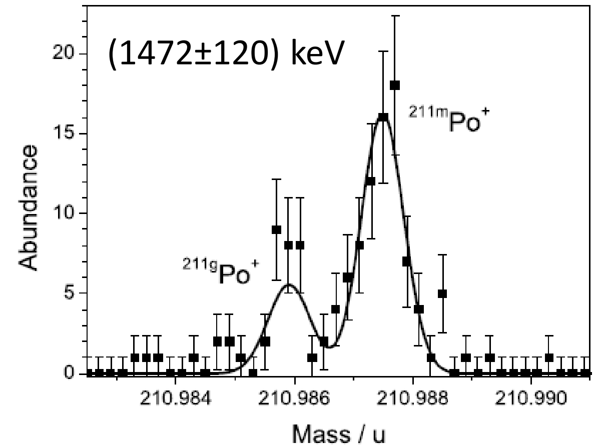

Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb

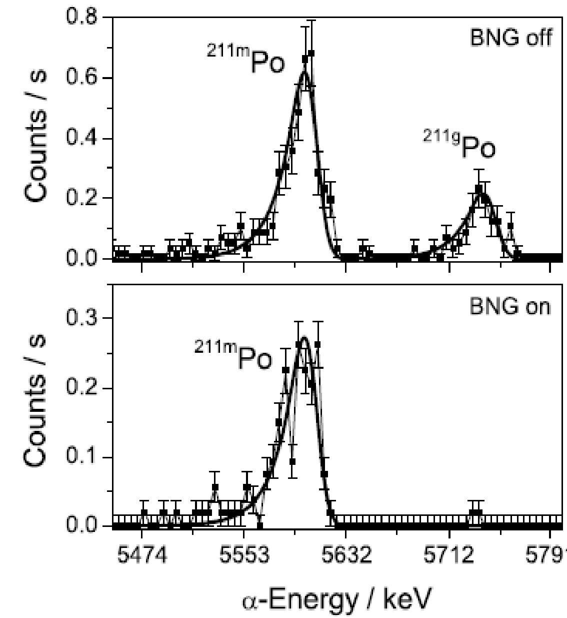
First spatial separation of a heavy ion isomeric beam with a multiple-reflection time-of-flight mass spectrometer

T. Dickel[a,b], W.R. Plaß[a,b,*], S. Ayet San Andres[b], J. Ebert[a], H. Geissel[a,b], E. Haettner[a,b], C. Hornung[a], I. Miskun[a,b], S. Pietri[b], S. Purushothaman[b], M.P. Reiter[a], A.-K. Rink[a], C. Scheidenberger[a,b], H. Weick[b], P. Dendooven[c], M. Diwisch[a], F. Greiner[a], F. Heiße[b], R. Knöbel[a,b], W. Lippert[a], I.D. Moore[d], I. Pohjalainen[d], A. Prochazka[b], M. Ranjan[c], M. Takechi[b], J.S. Winfield[b], X. Xu[a,b]

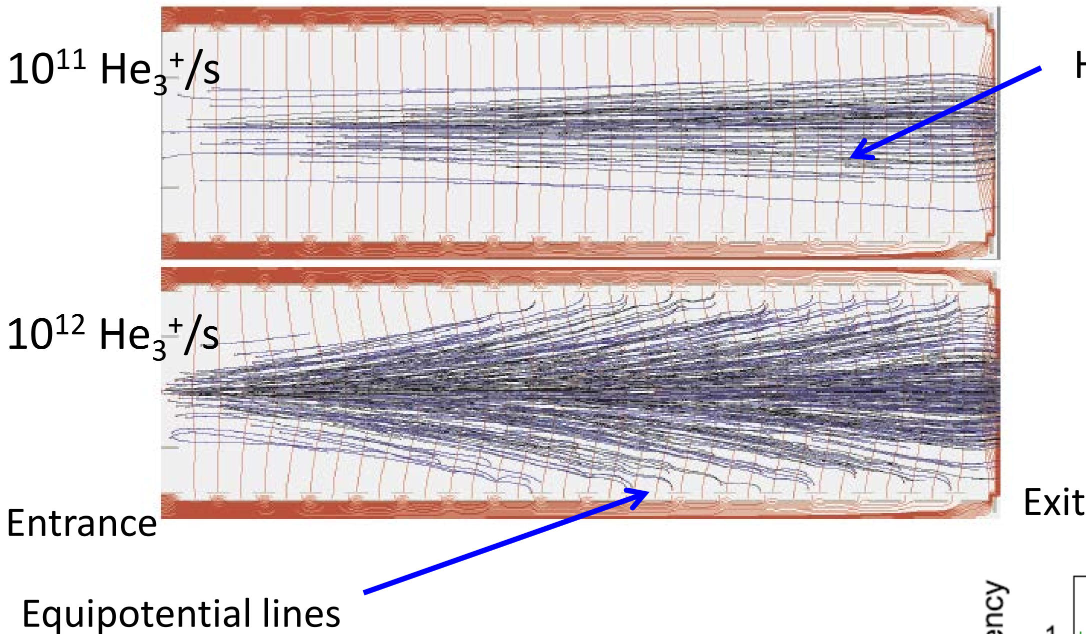








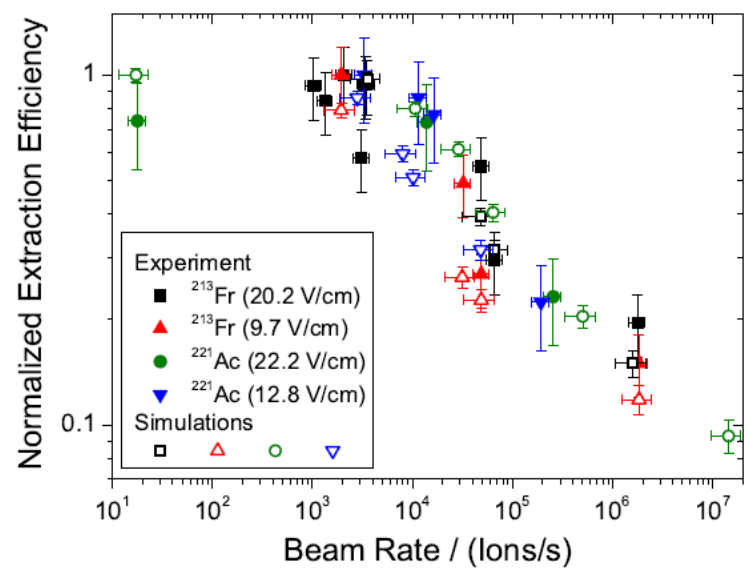
Rate capability of the stopping cell



1 stopped ion creates ~10^7 He ion-electron pairs

Deflection of ions;
defocusing of electric field;
→ reduced extraction efficiency,
→ reduced extraction time.

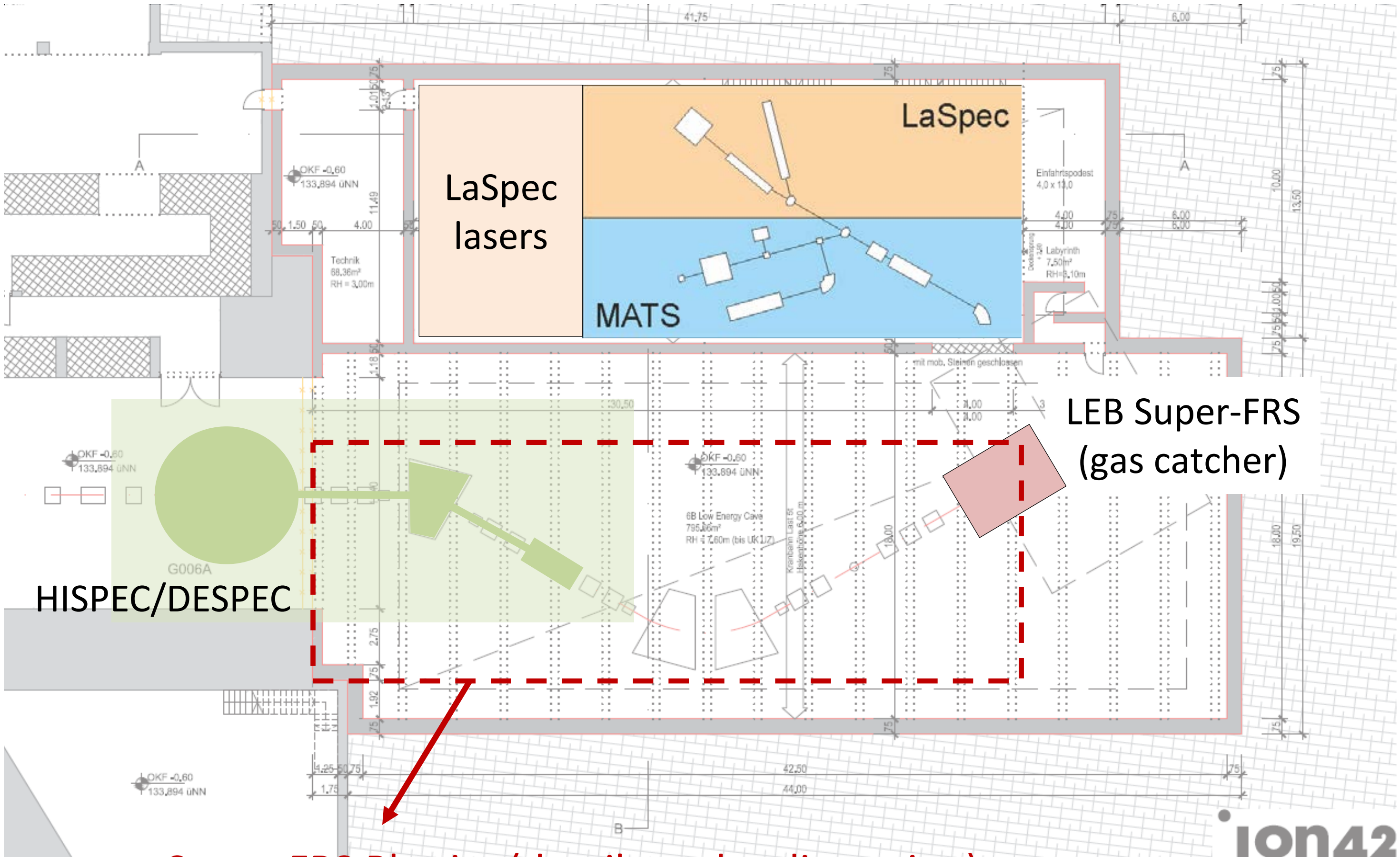
- Extraction efficiency constant up to a rate of 10^4 ions/s
- Drops to 10% of original value at 10^7 ions/s
- Gain in rate for factor of 2 increase in DC field strength only 40%
- Reduction due to space charge effects along the DC cage



M.P. Reiter et al., accepted for publication in NIMB (2015)

The Low-Energy Branch cave - space

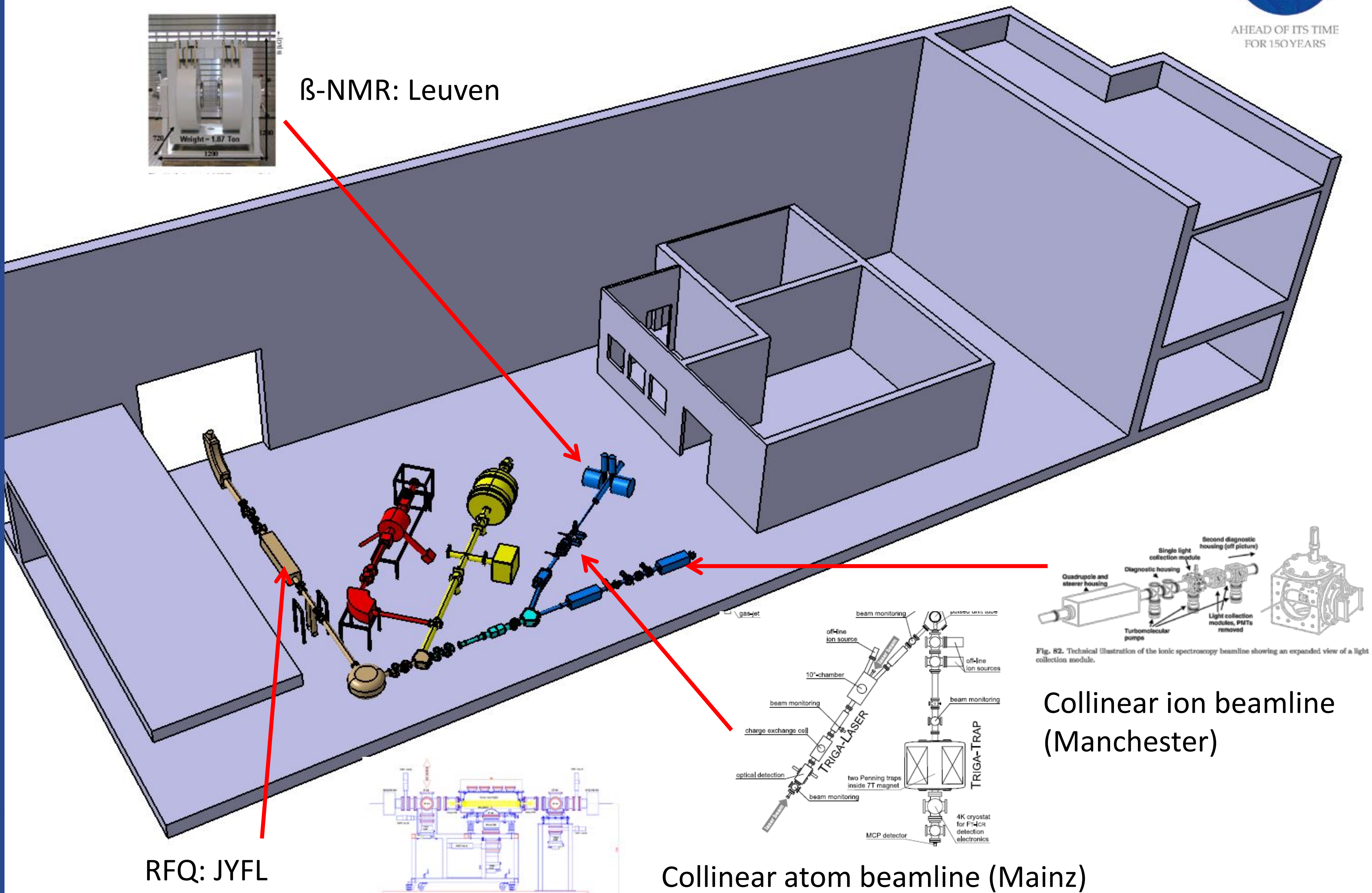
Presently under discussion (LEB infrastructure meetings)



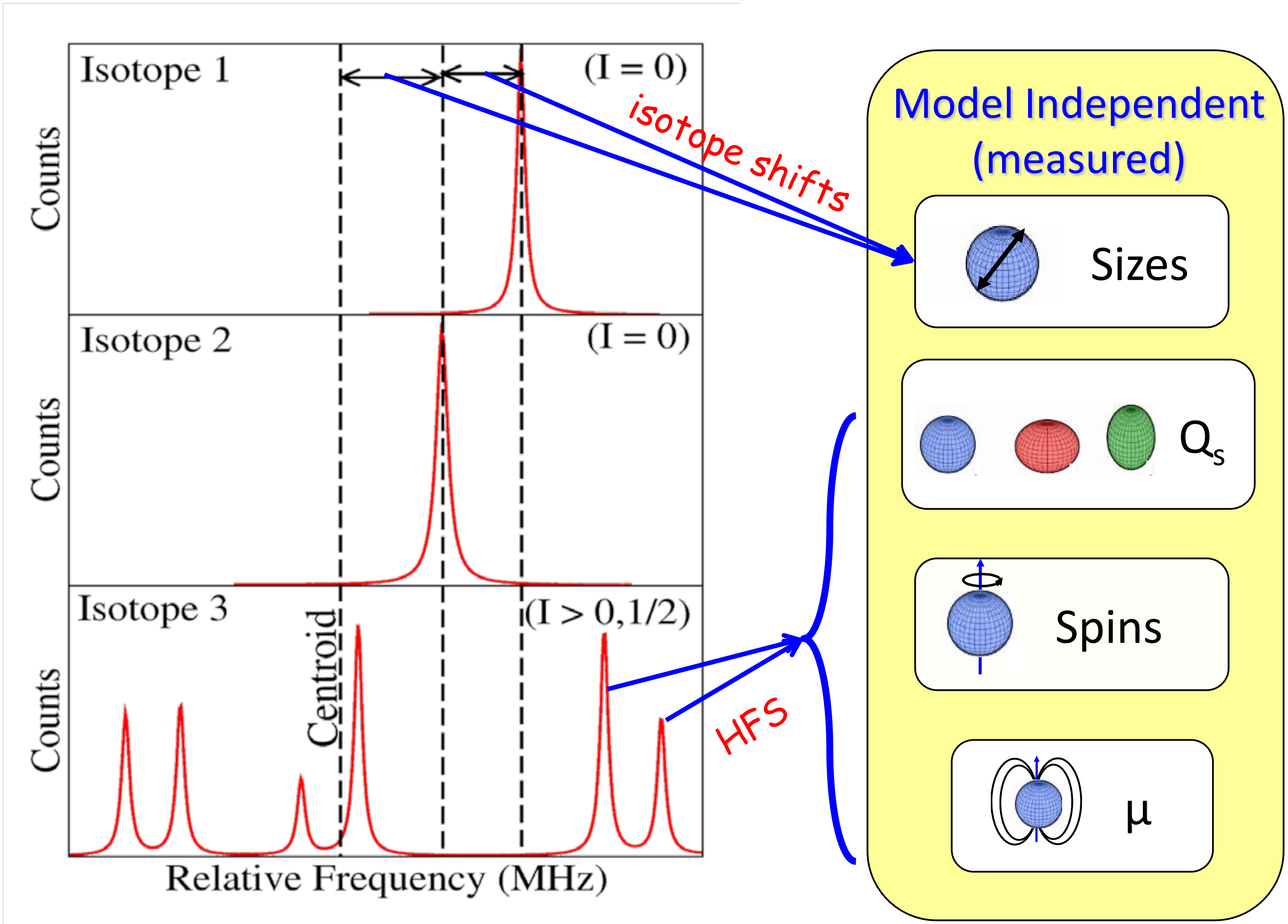
+ Super-FRS Physics (details under discussion)

+ energy buncher (as part of accelerator cost-book)

MATS & LaSpec at the LEB

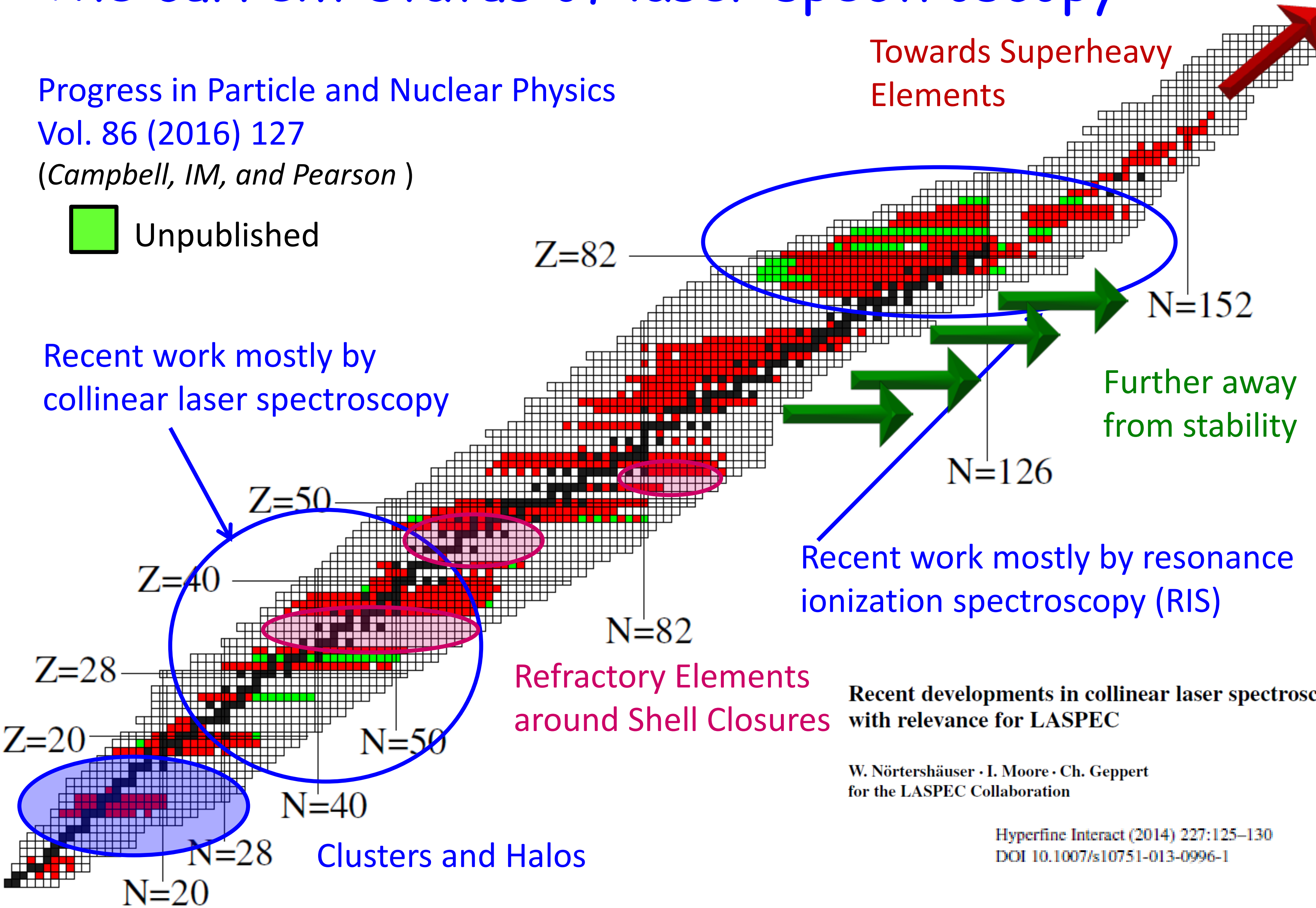


Probing the nuclear fingerprint on the atom



The current status of laser spectroscopy

Progress in Particle and Nuclear Physics
Vol. 86 (2016) 127
(*Campbell, IM, and Pearson*)



Recent developments in collinear laser spectroscopy with relevance for LASPEC

W. Nörtershäuser · I. Moore · Ch. Geppert
for the LASPEC Collaboration

Hyperfine Interact (2014) 227:125–130
DOI 10.1007/s10751-013-0996-1


WANTED
Schrödinger's Cat
Dead
and Alive
Thanks for your attention!
C. Jesch